GENERAL DISCUSSION AND CONCLUSIONS

This section presents the overall findings and general trends that became apparent in the Camera Car Study. Selected findings from other TravTek studies and previous research are also presented here to provide additional insight into the use of the TravTek system. For an issue-by-issue discussion of the results of the Camera Car Study, refer to the individual issue sections.

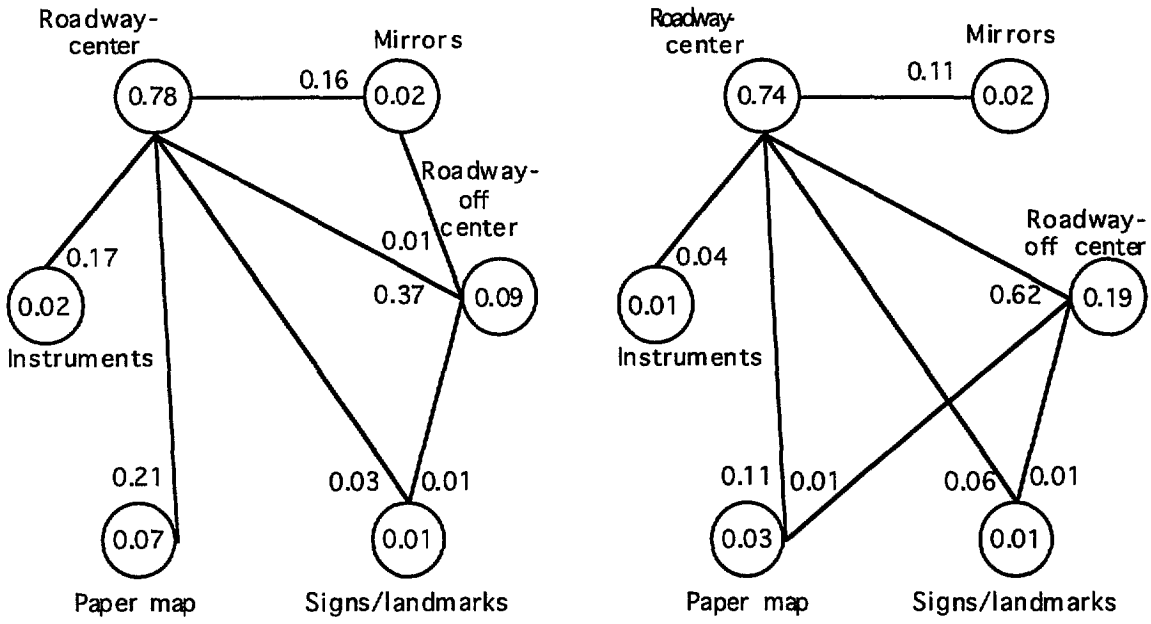
The eye glance data revealed several findings. Increases in visual attention by a navigation condition drew attention from left and right roadway scanning, a potentially valuable accident avoidance resource. The TravTek conditions without voice required a relatively high demand on visual attention, particularly in the case of the route map without voice. "Visual attention" in this context is operationally defined as the total amount of eyes-off-the-road time required to navigate to a destination. The TravTek turn-by-turn route guidance condition with voice required less single display glance time than the route map without voice, paper direction and paper map control conditions. The addition of voice, for both turn-by-turn and route map visual display conditions, substantially reduced visual attention requirements and was clearly beneficial to navigating drivers. The paper map condition required the least amount of visual attention overall, however the experimenter encouraged strategic behavior in this condition which may be absent outside of the context of this study. The paper map was most difficult to use, especially for older drivers.

Due to resource limitations, a true driving baseline condition consisting of driving on a familiar route was not included in the Camera Car Study despite its inherent advantages for comparison of measures. However, a baseline comparison can be made for eye scanning behavior between the Camera Car Study and a previous instrumented vehicle evaluation of the Etak Navigator conducted by Antin, Dingus, Hulse and Wierwille.(3) Antin and his associates compared the Etak system to a paper map control condition and a memorized route baseline condition. The study provided link diagrams for eye scanning behavior similar to the ones discussed in this report. Two differences between the diagrams were the glance categories identified and the use of glance times instead of glance probabilities. In order to make direct comparisons between the two studies, the TravTek link diagrams were converted to the format used in Antin et al.(s) A comparison of the paper map conditions between the two studies appears as figure 133.

As shown in figure 133 there are a number of similarities between the eye glance behavior while using a paper map in the two studies. In particular, the amount of time spent scanning the forward roadway, mirrors, signs/landmarks, and instruments is quite similar. Two notable differences are the amount of time spent scanning the roadway off-center and the paper map. Recall that in the Camera Car Study, drivers were encouraged to write down a list of instructions as they studied the paper map. This was not the case in the Etak study. The fact that TravTek camera car subjects used a list most of the time instead of referring to the map while driving probably explains these differences in visual scanning.

A second interesting meta-comparison between studies is shown in figure 134. This comparison shows the Etak Navigator and the TravTek route map without voice conditions. The Etak Navigator consisted of a monochrome moving map display with no route provided, and smaller font than the TravTek display, among other differences. As shown, mirror, sign/landmark and instrument scanning behavior was similar. Note, however that in the TravTek condition, less time was spent scanning the navigation aid and more time was spent scanning the roadway center and off-center locations. This difference may well have been due to the display differences described above. In particular, the Etak

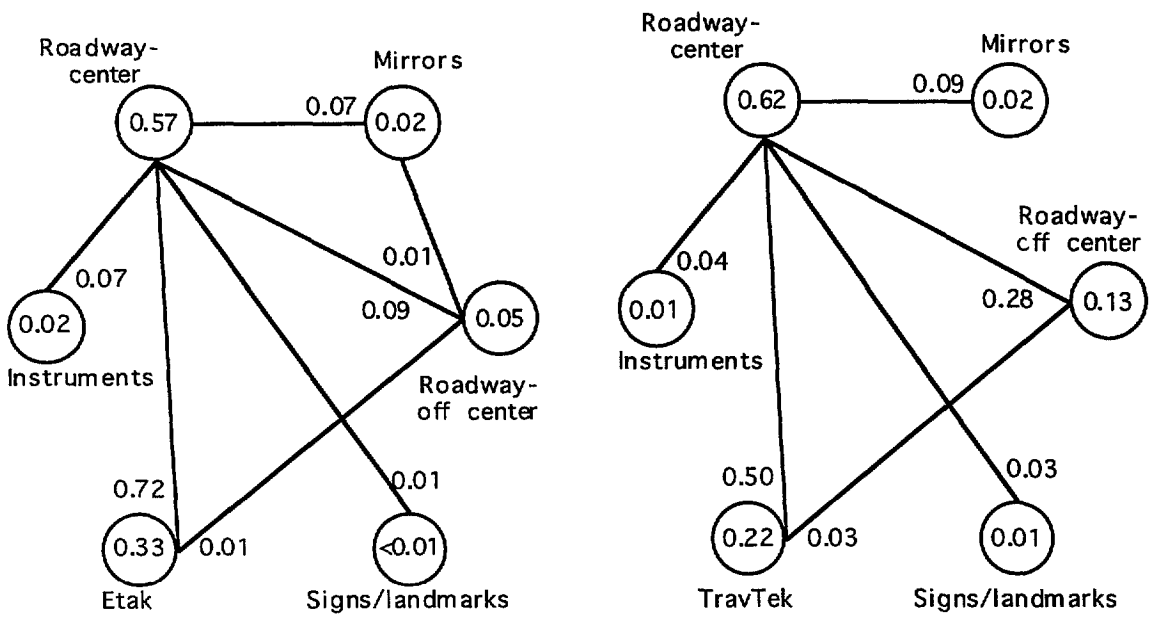
system required the drivers to plan their routes while in-transit.[3] This additional task may have resulted in the increased glance time to the Etak navigation display.



Etak Paper Map Condition [3]

TravTek Paper Map Condition

Figure 133. Eye glance link diagrams for the TravTek Camera Car Study and Etak Navigator Study paper map conditions.[3]



Etak Condition

TravTek Route Map Without Voice Condition

Figure 134. Link diagrams for the Etak navigator and TravTek route map without voice conditions.[3]

Given that the above comparisons provide some indication of the validity of contrasting these two studies, the baseline driving condition used for the Etak Study may provide valuable insight into the TravTek Camera Car Study conditions. The Etak memorized route condition consisted of drivers instructed while in-transit by the in-vehicle experimenter, and subsequent driving of the route until it was completed error-free.(3) The eye-scanning link diagram for this condition is shown in figure 135.

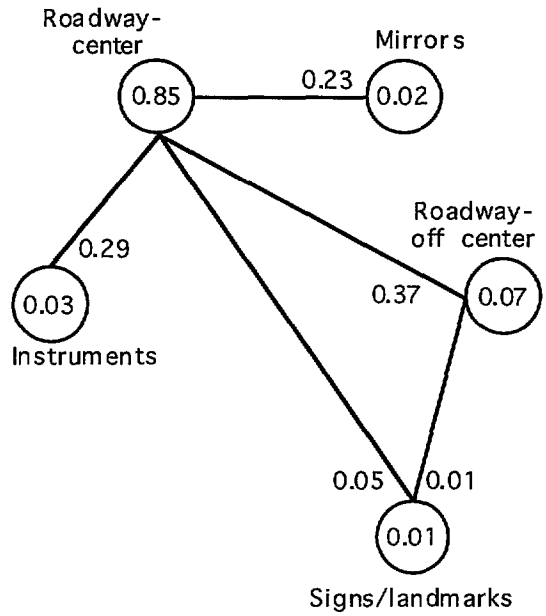


Figure 135. Link diagram for the Etak memorized route condition.(3)

As shown in figure 135, the Etak baseline condition resulted in a high percentage of time devoted to the forward roadway. Note, however, that the roadway off-center percentage was lower than the TravTek route map without voice condition shown in figure 134. This may be due to a difference in the operational definition of "roadway off-center" or to the fact that subjects were not really navigating in the memorized route condition. That is, in the navigation conditions, subjects may have been scanning the roadway off-center more to find signs and landmarks (as opposed to *looking* at signs and landmarks as shown in the link diagram). Support for this hypothesis can be found in comparisons between the Etak paper map and baseline conditions (figures 134 and 135). Subjects had more roadway off-center scanning in the paper map condition.

Figure 136 shows the TravTek paper direction list control condition. As shown in a comparison between this figure and figure 133, the paper direction list most closely approximates the TravTek paper map control condition in eye scanning behavior. This similarity may be due in part to the protocol that encouraged subjects to write a list of instructions and follow them in the TravTek paper map condition. The TravTek turn-by-turn with voice condition is also very similar in eye scanning behavior to the TravTek paper direction list (figure 136).
Figure 137 shows the converted link diagrams for the remaining TravTek conditions. As shown by comparisons between figure 137 and previous figures in this section, these conditions have more roadway center and off-center glance time than either of the moving map conditions without voice (figure 134). The TravTek turn-by-turn without voice and

route map with voice conditions are similar to one another and fall between the route map without voice and turn-by-turn with voice conditions in apparent visual attention demand.

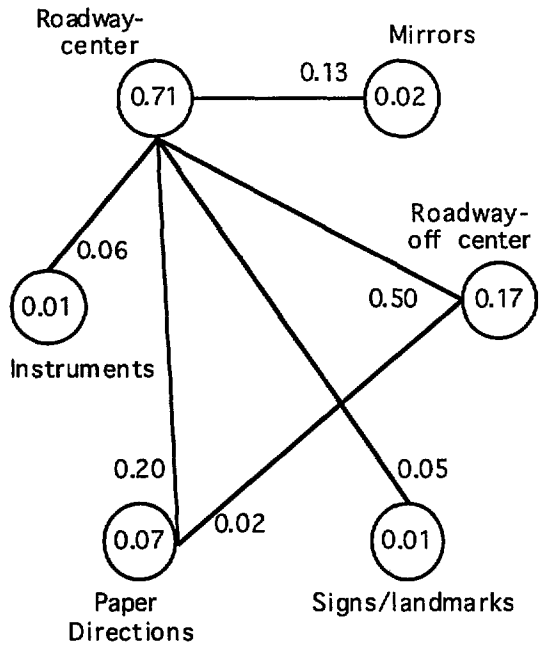


Figure 136. Link diagrams for the TravTek paper direction control condition.

In comparing all of the navigation conditions for both the Etak and TravTek studies to the Etak baseline condition (figure 135) it is apparent that navigating to an unknown destination results in different eye scanning behavior than driving to a known location. Specifically, a very large percentage of time is spent glancing to the roadway center while only driving. In fact, less time is spent scanning the left and right roadway when no navigation task is involved. Given this behavior, it is apparent that driving performance data such as lane deviations and safety errors will be improved when no navigation task is involved while driving. As was shown in the results of the Camera Car Study, such measures will further degrade when visual attention demand is increased by the inherent design of a navigation aid.

The number of unplanned lane deviations varied somewhat between TravTek conditions; the paper direction list, route map with voice, and route map without voice conditions had approximately 40 lane deviations each, while the paper map, turn-by-turn without voice, and turn-by-turn with voice conditions had approximately 30 each. Single display glance time in previous research has correlated with lane position variance.[25] The TravTek turn-by-turn conditions had relatively short single display glance times which may explain the fewer number of lane deviations for these conditions. Drivers drove slower in the paper map control condition and had the fewest display glances compared with the other navigation conditions. This might explain why there were relatively few lane deviations in this condition.

The paper map control condition had the slowest mean speed, which was indicative of the relative ease that drivers had using the other five conditions to navigate. These five conditions also showed an improvement in navigation performance exhibited by the time taken to plan and drive to a destination and in the number of navigation errors, in comparison to the paper map condition.

The subjective workload measure indicated that the paper map control and route map without voice conditions were the most difficult to use. The amount of visual attention required by a configuration appeared to be one contributing factor to this workload rating. The highest visual attention demand was created by the route map without voice condition, as described above. Relatively speaking, drivers were required to look more frequently and for longer durations at this display configuration to retrieve the required information. This workload was substantially reduced when voice guidance was added in conjunction with the route map display.

In contrast, the paper map condition required little visual attention (based primarily on number of glances), even though the single display glance time was relatively high. However, the number of abrupt braking maneuvers, mean speed, and workload ratings indicated that the paper map intruded upon the driving task. It is apparent that this condition required high "cognitive attention" on the part of the driver. It was apparent that required navigation information could not be visually accessed in the paper map conditions as easily as in the other conditions. Therefore, the cognitive attention could have been caused by the need to hold more inforrnation in memory.

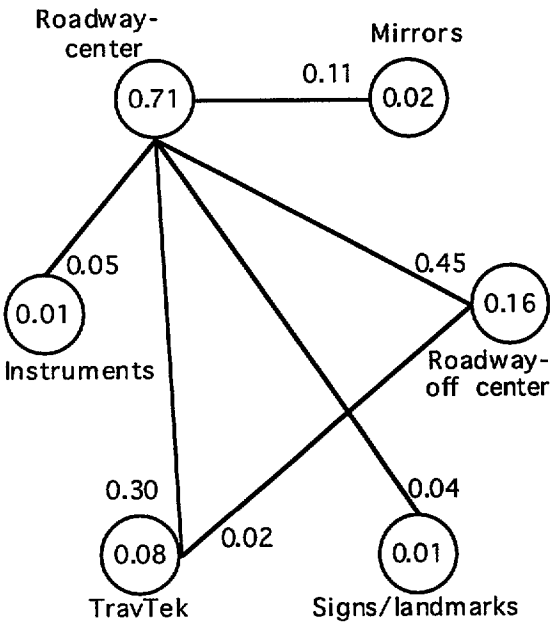
The usability analysis results indicate that the TravTek navigation conditions were easier to use than the paper map control condition. These results also indicate that the textual paper direction list was as easy to learn and use as other TravTek navigation configurations. However, it should be noted that in the direction list condition, drivers did not have to plan their routes as they usually would. In addition to longer planning and trip times for the paper map condition, significantly more time was spent stopped relative to the other navigation conditions. The paper map control condition had the highest number of lost drivers as well. This indicates that the overall usability of the TravTek and paper direction conditions was higher than the paper map control. The route map without voice was the most difficult TravTek condition to learn and use, which was due primarily to the difficulty **drivers encountered identifying turns.**

When comparing these findings with the subjective opinions of users in the Rental User Study (shown in figures 138 and 139), it was found that users felt positive about the usability of the route map and turn-by-turn conditions. While drivers in the Camera Car Study rated the workload significantly higher for the route map without voice condition, this was not apparent in the overall ratings of usability from the Rental User Study.

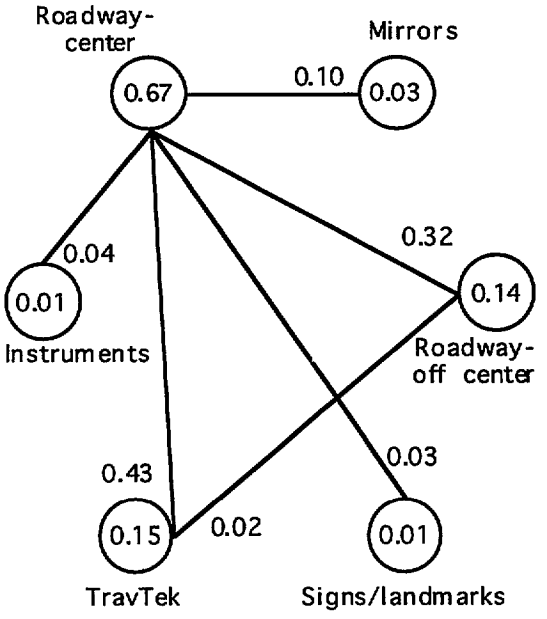
Figure 140 shows a direct comparison made by the Rental Users Study users between the TravTek configurations. The camera car driving performance, navigation performance, and usability analysis results indicate that voice was a positive feature when used with either of the visual display configurations. This finding was supported by the renters' opinions. Note that a voice only condition, was rated lower than the combined conditions and rated the same as the visual only conditions.

For the Camera Car Study, the in-vehicle experimenter observed that novice drivers preferred the voice over the nonvoice conditions. Many local users reported that once they learned the system, voice was no longer needed for routine driving. However, if a driver programmed an unfamiliar route, the voice was turned back on. Younger local user drivers also reported that they frequently switched between the turn-by-turn route guidance and the route map. All drivers reported that the route map provided good route planning awareness, while the turn-by-turn guidance display provided good immediate turn guidance.

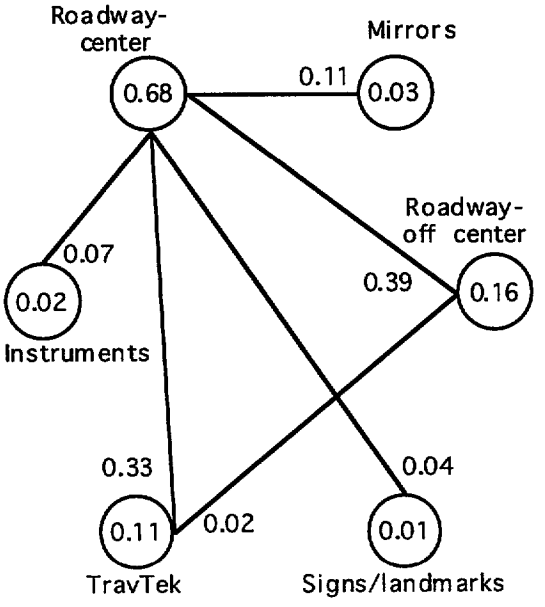
These observations are consistent with the Rental User Study and local users' study results. Figures 141 and 142 show that both renters and local users used the guidance screen more often than the route map.[28]



TravTek Turn-by-Turn With Voice Condition



TravTek Turn-by-Turn Without Voice Condition



TravTek Route Map With Voice

Figure 137. Link diagrams for TravTek turn-by-turn conditions and route map with voice condition.

Also consistent with the usability findings of the Camera Car Study is the amount of time that the TravTek voice was activated by renters (see figure 143) and local users (see figure 144). The figures show that both groups found voice to be useful and/or desirable, although less so by the local users.

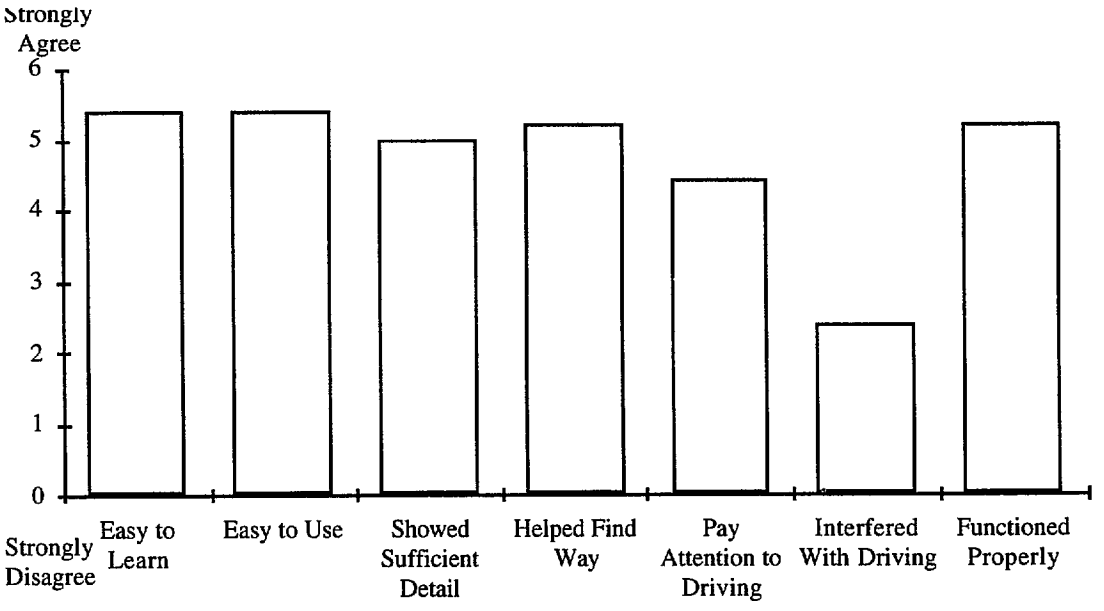


Figure 138. Questionnaire ratings of the usability of the TravTek route map from the Rental User Study.

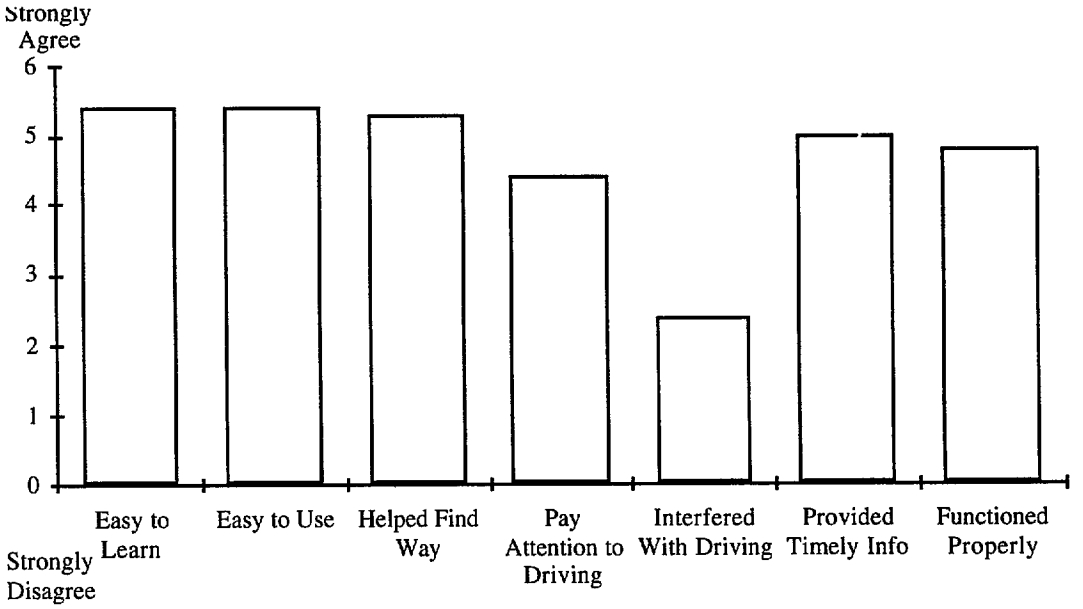


Figure 139. Questionnaire ratings of the usability of the TravTek guidance display from the Rental User Study.

The safety analysis results for the TravTek configurations used in the Camera Car Study, show differences in accident potential across the different display types. Keep in mind that

while the attention demands required by the TravTek and control conditions may have the potential for risk, this should be viewed in the context of the entire TravTek operational field test which resulted in no crashes thought to be due to TravTek and apparently no increased safety exposure. The TravTek route map without voice configuration appears less safe than the other navigation conditions tested. This statement is based on greater numbers of safety-related errors and near misses that occurred for the route map without voice when compared to the other navigation conditions, including the paper map and paper directions. The types of errors committed, revealed that the route map without voice visually overloaded drivers and distracted them from the primary task of vehicle control. Specific errors for the route map condition were unsafe circumstances during glances over 2.5 s, lane deviations, and inappropriate speed. These are all indicators of high visual attention demand.

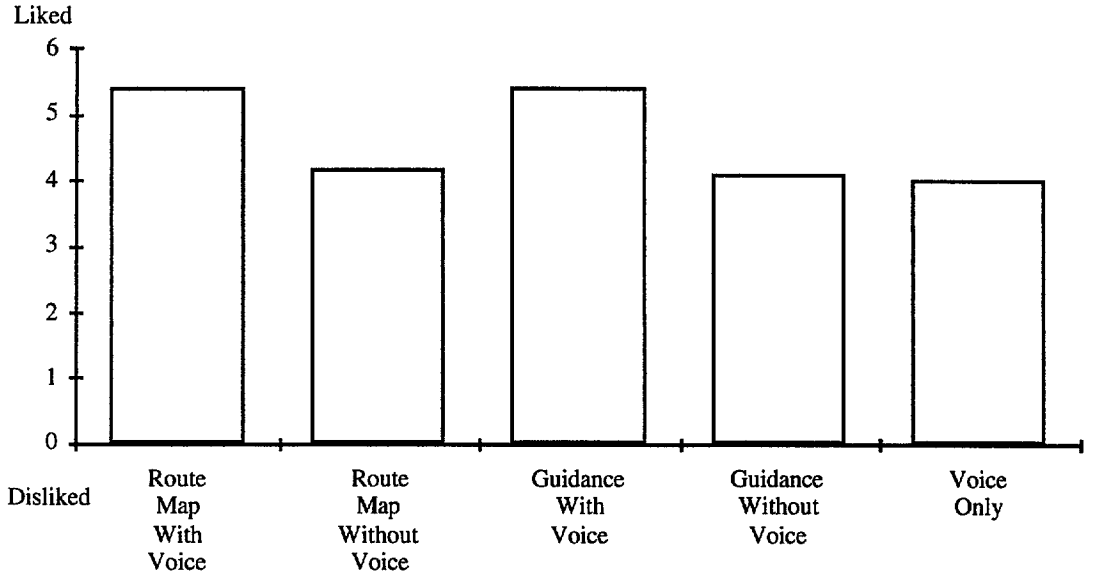


Figure 140. Questionnaire comparison of the TravTek route guidance modes from the Rental User Study.

The above safety findings must be taken in context with the results shown in figures 141 through 144. That is, TravTek renters and local users, when given a choice at the touch of a button, actually used the route map without voice condition only a small percentage of the time. It must also be taken into consideration that the route map condition provided unique and valuable information in selected circumstances (such as when the vehicle was off-route). The route map without voice was inherently less safe when it was the only option available to drivers; however, when it was provided with turn-by-turn information access, the results were less dramatic.

The turn-by-turn with voice condition had a comparable number of safety-related errors compared to the conventional methods of navigating. In fact, the mental workload ratings show that turn-by-turn with voice faired better than the paper map condition for drivers experiencing overload. In addition, older drivers had a higher number of safety-related errors while using the paper direction list than while using the turn-by turn with voice condition. Given this finding, there are no safety-related reasons for not implementing this display in its present state of development.

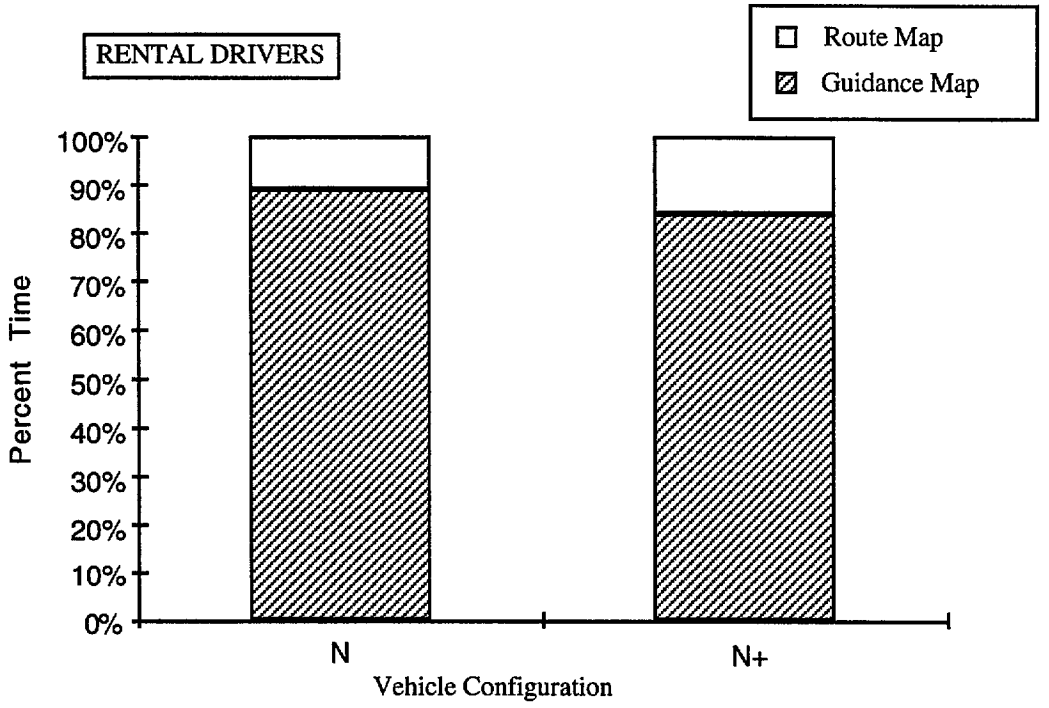


Figure 141. Percentage of time renters spent using the TravTek visual configurations.[28]

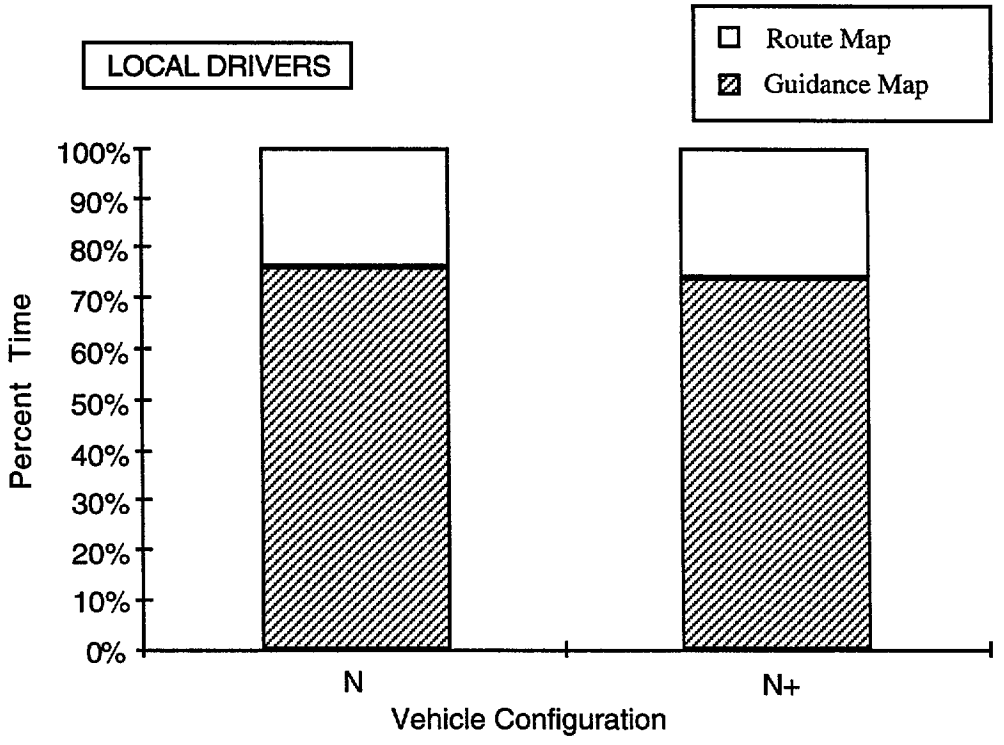


Figure 142. Percentage of time local users spent using the TravTek visual configurations.[28]

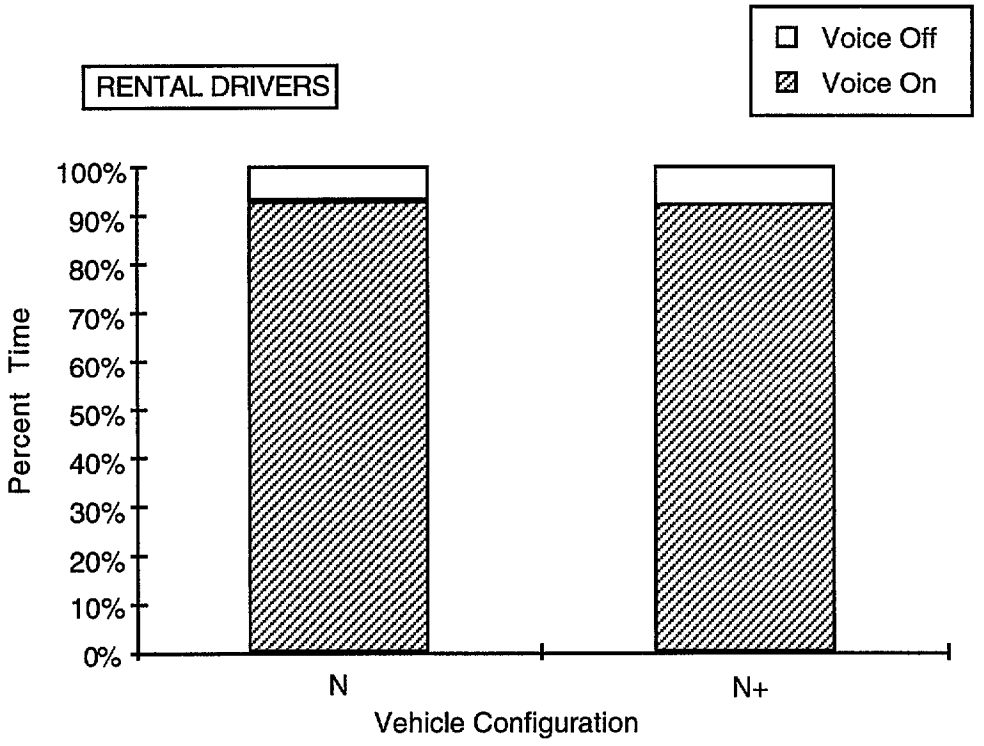


Figure 143. Percentage of time renters spent using the TravTek voice configurations.[28]

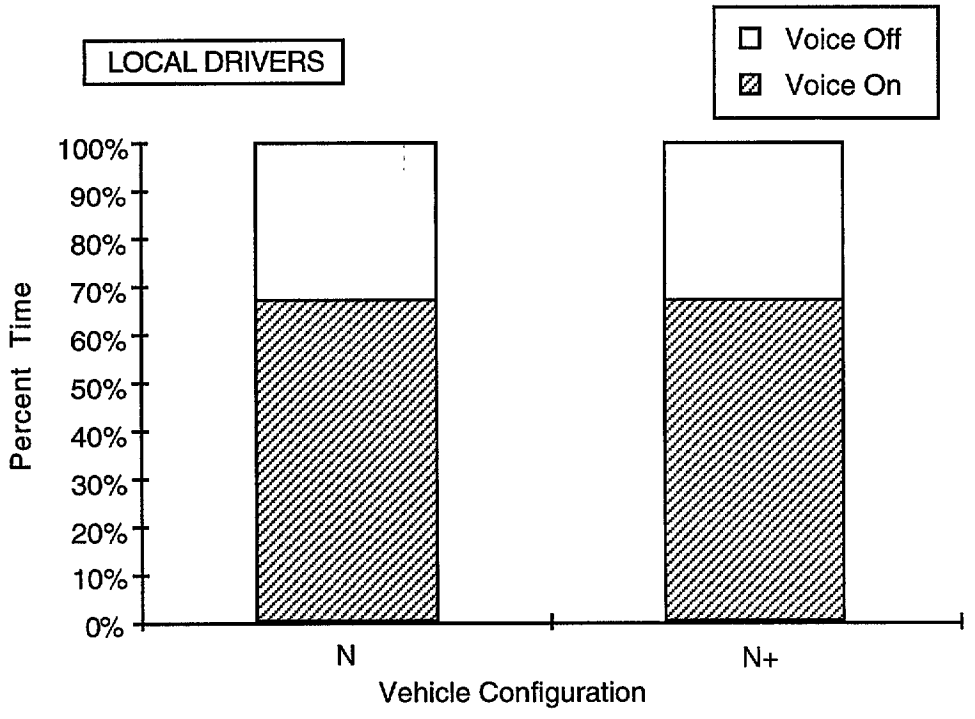


Figure 144. Percentage of time local users spent using the TravTek voice configurations.[28]

It was determined that the number of safety-related errors were reduced with the addition of the element of voice to the visual navigation aids. Recall that the turn-by-turn with voice faired well, while the safety-related errors for turn-by-turn without voice increased by a moderate number. When voice was added to the route map condition, it was comparable to the turn-by-turn without voice interface in number of safety-related errors. While these two configurations had more error occurrences than the conventional methods of navigating, the frequency of those occurrences was low enough so that they may still be comparably safe.

Note that in all navigation conditions, including paper map and paper direction control conditions, the task of navigation while driving was a difficult task. Despite this fact, few truly unsafe driving instances were exhibited. There were also relatively few near misses, and no accidents. The most objective method possible was used to analyze the differences in safe use of the navigation configurations, but interpretation of the results must take the method of analysis into consideration. It is encouraging to note, that drivers made adjustments and compensated in a variety of ways in order to avoid accidents. However, this compensation capability makes it difficult to estimate the actual accident potential of using such systems.

Driving performance results show that drivers improved with TravTek navigation system experience. After gaining this experience, drivers made fewer and shorter glances to the navigation display. This result indicates that experienced drivers developed strategies to get the information they needed from the system with less effort than novice drivers. This means that experienced drivers can spend more time scanning the roadway environment, since less visual attention is required. This conclusion is supported by the finding that experienced drivers made fewer lane deviations and made more glances to the roadway environment than novice drivers. Ideally, the more time drivers have to scan the roadway environment, the safer the driving task will be. This safety-related finding was supported in that experienced drivers had fewer safety-related errors. This was particularly true of the route map without voice condition. When drivers gained experience using the system, there was a comparable number of safety-related incidents across conditions. In contrast, novice users had substantially higher numbers of safety-related errors in the route map without voice condition than in any of the other conditions.

Experienced drivers spent less time driving to their destinations than novice drivers. When both trip planning time and time required to drive to the destination were added together, it was determined that experienced drivers were able to reach their destinations faster . This result indicates that drivers became more efficient with system experience. Experienced drivers also spent less time stopped as they drove to their destinations.

The overall results indicate that age played a role in how drivers performed while using TravTek. This is consistent with previous research.(19) Older drivers generally had poorer driving and navigation performance than the other two age groups tested. Older drivers compensated for their poor performance by driving slower and more cautiously. However, despite this compensation, older drivers had a larger number of safety-related incidents. These errors were not uniform across error classifications. Older drivers had the highest number of incidents related to long glances away from the roadway, inappropriate slow speed, intersection errors, and lane deviations. Older drivers did however, have a lower number of braking errors than the youngest age group, and no inappropriate reactions to external events.

Older drivers (65+) consistently showed lower navigation performance, longer eye glance durations, and longer planning and trip times. Note, as the attention demand of a navigation display increased, all drivers reduced the amount of time spent scanning the left and

right forward view. For older drivers this is important, since their useful field of view is slowly reduced with age.(27) That is, as drivers age, their ability to process and respond to information in their periphery diminishes. This decrement, in conjunction with reduced scanning behavior, may increase the accident potential of older drivers under conditions of high visual attention demand. However, turn-by-turn route guidance especially with voice greatly improved their performance. Older drivers are particularly vulnerable to attention demand during driving, but they can also benefit from well-designed information systems. Overall, the older drivers in this study benefited from the route planning and route guidance functions made available by TravTek. The use of TravTek resulted in improved trip-planning times. Older drivers had the most difficulty with paper maps. Using TravTek turn-by-turn route guidance with voice, reduced the number of lane deviations made by older drivers to the level of younger age drivers. Supplementing visual route guidance displays with voice resulted in increased right and left roadway glances.

Several interesting results were discovered when determining the effects of area familiarity. First, visitors drove slower and more cautiously than local users. However, it was found that visitors time-shared to a greater degree between navigation and driving tasks by making more frequent glances to the navigation conditions. This might be due to novice local users being more knowledgeable in their familiar surroundings. Second, there was no difference in planning and driving times between visitors and local users. Third, novice local users went off route twice as often as visitors and became lost more often. The in-vehicle experimenter noted that this effect probably occurred because the local users had prior expectations and assumptions about the route as opposed to carefully and unquestioningly following the instructions given by the navigation aid.

CONCLUSIONS

In conclusion, the TravTek route map without voice had the greatest impact on the driving task and had the most safety-related errors of all the navigation conditions tested. However, the negative safety aspects of this display are tempered substantially by driver experience and the addition of voice guidance. In addition, other TravTek studies have shown that drivers use voice and turn-by-turn guidance most of the time while navigating. Therefore, giving drivers a choice of navigation conditions will further mitigate this safety finding.

The paper map control condition tested by this study proved to be the least usable means of navigation, and consequently the other five conditions resulted in better navigation performance. Drivers that used a paper map took almost twice as long (on average) as most of the other navigation conditions to reach destinations designed to be 20 min away. The route map without voice was also shown to be less usable than the other TravTek conditions or the paper direction list control condition.

A primary finding of this research is that turn-by-turn guidance information, whether presented verbally, in a textual list, or by a graphic display, enhances navigation performance, usability, and/or safety when compared to alternatives which provide only holistic route information. For this study, the TravTek turn-by-turn with voice condition and a paper direction list (featuring a large and legible font and distance to turn information), provided the best overall performance. The TravTek turn-by-turn without voice and route map with voice conditions also provided reasonable performance overall.

Experience with the TravTek conditions led to improved driving performance, navigation performance, and safety. This was particularly true in the case of the route map without voice condition, which had the most safety-related errors for novice users, but had

comparable levels of safety-related behaviors for experienced users. It is interesting to note, that drivers also improved paper-map navigation performance with experience. After completing the novice run, subjects' apparently planned more carefully and prepared better notes using the paper map condition.

Because older drivers generally had poorer driving and navigation performance than the other two tested age groups, they compensated for this by driving slower and more cautiously. However, they still had a larger number of overall safety-related incidents. Older drivers benefited most from turn-by-turn route guidance with voice.

A counter-intuitive finding was shown in the area familiarity analysis . The novice local users had poorer driving and navigation performance than the visitors. Visitors drove more cautiously and slower than the local users. It is clear that the visitors compensated for increased workloads (due to their unfamiliarity with an area), by exhibiting careful and prudent behavior and driving more cautiously.